concentration at much higher Reynolds numbers than achievable numerically, but the concentration factor can be so large that the local particle mass density can exceed that of the gas, and the feedback effect of the particle phase on damping the gas turbulence must be considered before further modeling efforts can proceed. A cascade model of a process that is capable of reproducing the way concentrations of particles emerge as energy flows down the turbulent cascade, or inertial range, is being developed to better understand the effects of heavy mass loading on turbulence and TC. The cascade model is parameterized by partition functions or "multipliers" that are only statistically defined, but whose probability distribution function can be fit to present numerical results for mass-loaded turbulent fluids. In other words, the multipliers appropriate for densely particle-enriched regions where the turbulent kinetic energy and/or vorticity might be damped could be different from the multipliers in "normal" regions where mass loading is negligible. The dependence of these multipliers on the local gas and/or particle density properties is now being determined by making extensive use of new runs of a scalar field particle code (rather than the previous Lagrangian particle code) on the Ames Origins 2000 facility.

In FY00, Ames researchers also developed a scenario to help explain a new phenomenon found in chondritic meteorites by collaborators at Stanford University and the University of Hawaii. The observation is of an abundant class of iron/nickel metal grains with chemical and crystallographic properties that define their growth and cooling times simultaneously. The scenario developed visualizes a very hot, early, perhaps inner stage of the protoplanetary nebula, rather different from the environment in which more familiar chondrites form. In this dense, hot region, strong convection plumes rise toward the surface of the nebula, cooling and condensing small metal and silicate particles much as raindrops or hailstones condense in upwelling thunderstorm plumes on Earth. Some fraction of these objects are dispersed outward to cooler regions before being downdrafted again to their destruction. Although the theory adequately explains some properties of these unique meteorites, it is clear that deeply puzzling aspects remain unexplained.

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Planetary Rings

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In addition to the natural curiosity inspired by their exotic appearance, planetary rings present a unique dynamical laboratory for understanding the properties of collisional particle disks that might aid in the understanding of the accretion of the planets. Ames scientists are involved in numerous different aspects of planetary-ring studies.

An ongoing Hubble Space Telescope (HST) program to observe the rings while they "open up" as seen from Earth over the last five years (see figure) has produced over 100 images in a variety of filters. Analysis of these images using a newly developed surface-scattering code has led to the conclusion that the increasing redness of the rings that has been found to

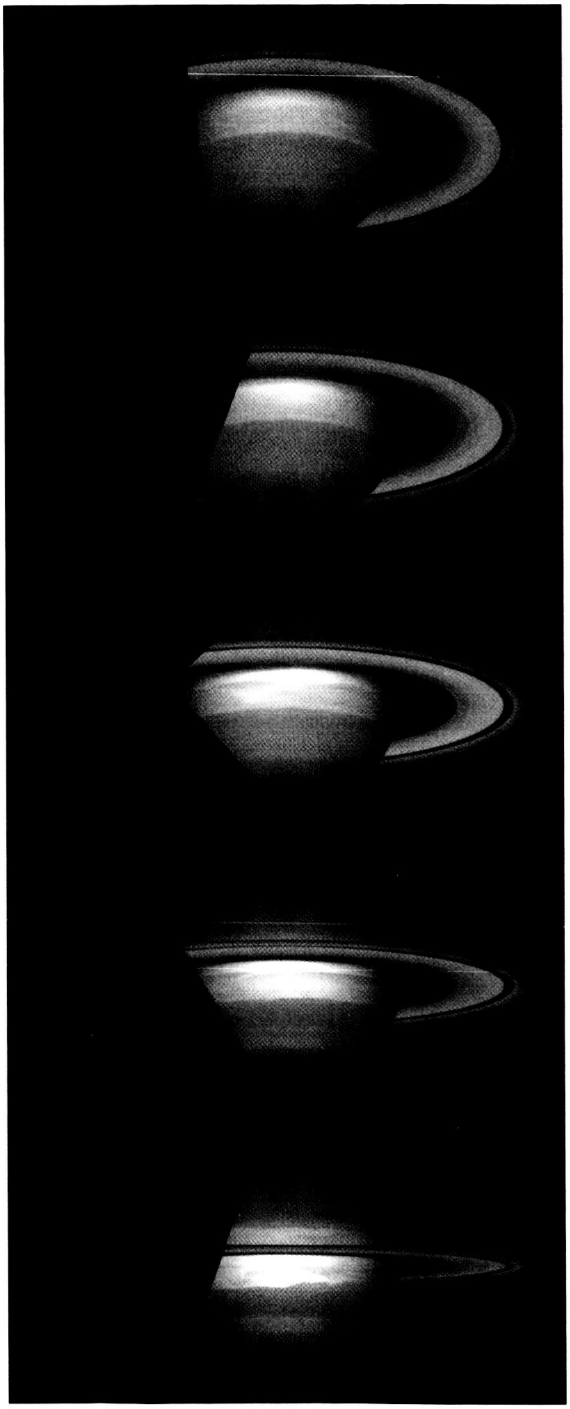

Fig. 1. HST observations of Saturn since 1996, during which time the ring opening angle has increased from about 4 degrees to about 24 degrees. The time sequence begins in the bottom image. Data of this quality are available in over eight color filters. Voyager data are of higher spatial resolution, but only three filters are available—fortunately they are nearly identical to three of the HST filters.

occur as the angle between the Sun and the Earth increases is caused by unusually rough surfaces on the ring particles. This theory supports the concept that a ring "particle" is actually an ensemble or aggregation of smaller "particles"—a lumpy snowman-like fractal structure. Further analysis will give insight into how this structure varies across the rings, on scales that can never be observed directly (tens of meters or less). In addition, this modeling and analysis has established that the abrupt brightening of the rings as the Sun-ring-Earth angle gets very small, which has been previously ascribed to the disappearance of shadows, is more likely due to optical interference effects within the grainy surface of individual particles. This result helps reconcile the brightening with dynamical expectations that the ring particles are collapsed into a fairly thin, dense layer because of inelastic collisions rather than being many particles thick as had been previously thought. This study also examined a discrepancy between Voyager and HST color observations of the rings, tracing it to an incorrect Voyager calibration. A direct comparison of Voyager and HST color data reveals that the two datasets are in very good agreement from the standpoint of spatial color variations. Variations of color, which trace out particle compositional variations, vary with radius and ring opacity in a way that is quite unusual and will be addressed in future analysis.

The systems of large (and small) regular moons that orbit the gas giant outer planets have always been cited as "solar systems in miniature," but their own origin has remained a puzzle. One recent area of interest is the two outer Galilean moons of Jupiter (Ganymede and Callisto), which are of very similar mass and size, yet have very different internal structures. A two-stage accretion scenario has been developed that postulates a long-lived, secondary accretion stage only for Callisto involving debris that forms in a very extended disk of material that extends far out beyond the boundaries of the current satellite system. A small amount of gas remaining in this disk causes solid material to drift slowly inward onto the outermost moon, accreting without providing much heating. In addition, a study of the thermal internal evolution of a realistic Callisto was carried out, including ice-phase-change boundaries and plastic ice convection, showing that a sufficiently slow accretion rate would indeed preclude melting of the icy component and prevent complete differentiation of the icy and rocky material.

Ames maintains the Planetary Data System Rings Node (http://ringmaster.arc.nasa.gov/), which archives and distributes ring data from NASA's spacecraft missions and from Earth-based observatories. The entire archive of images from the Voyager missions to the giant planets is now on line, with catalogs to help users find the images they need. Interactive search and geometrical visualization utilities are also available to assist Cassini scientists in planning observations of the rings during the upcoming tour (2004–2008). Ames also provides the Cassini project with the Interdisciplinary Scientist for Rings and Dust, who chaired the Rings Discipline Working Group this year as it worked through initial ring science sequence planning.

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Vortex Evolution in a Protoplanetary Disk

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The theory that planets form from a thin disk of dust and gas was first proposed in the 18th century and is now a generally accepted fact. The process by which planets actually emerge from this tenuous state is a subject of intense current study. Recent research points to vortex motion as a possible intermediary where dust particles are captured, concentrated, and finally accumulated by gravitational attraction. These mass accumulations gradually grow to kilometer-sized objects (planetesimals) and ultimately to full-sized planets. With the assumption that the disk can support a turbulent flow, it was shown that vortices arise naturally and persist as long as turbulent energy is present. Other possibilities are that vortices arise from certain instabilities in the rotating disk or from external impacts of clumpy infalling gas. In either case, coherent vortices could lead to important and far-reaching processes in the protoplanetary disk.

A research study is under way to determine the effect of vortices on the wave structure in a typical disk, which may also play a role in the planet-formation process. It is well-known that discrete vortices in a sheared flow do not retain their coherence. This coherence time depends on the local shear rate, the strength, and the size of the vortex. During the shearing epoch, and depending on the nature of the medium, a vortex can emit a variety of wave systems. In this study, the equations of motion have been simulated using a high-resolution numerical method to track Rossby and acoustic/shock waves. Rossby waves are slowly moving waves of vorticity generated in flows with large-scale vorticity gradients. Acoustic waves are waves of expansion and contraction that occur in all compressible media. The protoplanetary disk is a rotating compressible gas with a radially variable rotation rate. It can support both wave systems.